GROUNDBREAKING MARS SAMPLE RETURN FOR SCIENCE AND HUMAN EXPLORATION. B. A. Cohen, NASA Marshall Space Flight Center, Huntsville AL 35812 (Barbara.A.Cohen@nasa.gov).

Introduction: Partnerships between science and human exploration have recent heritage for the Moon (Lunar Precursor Robotics Program, LPRP) and near-earth objects (Exploration Precursor Robotics Program, xPRP). Both programs spent appreciable time and effort determining measurements needed or desired before human missions to these destinations. These measurements may be crucial to human health or spacecraft design, or may be desired to better optimize systems designs such as spacesuits or operations. Both LPRP and xPRP recommended measurements from orbit, by landed missions and by sample return.

LPRP conducted the Lunar Reconnaissance Orbiter (LRO) and Lunar Crater Observation and Sensing Satellite (LCROSS) missions, providing high-resolution visible imagery, surface and subsurface temperatures, global topography, mapping of possible water ice deposits, and the biological effects of radiation [1]. LPRP also initiated a landed mission to provide dust and regolith properties, local lighting conditions, assessment of resources, and demonstration of precision landing [2]. This mission was canceled in 2006 due to funding shortfalls. For the Moon, adequate samples of rocks and regolith were returned by the Apollo and Luna programs to conduct needed investigations.

Many near-earth asteroids (NEAs) have been observed from the Earth and several have been more extensively characterized by close-flying missions and landings (NEAR, Hayabusa, Rosetta). The current Joint Robotic Precursor Activity program is considering activities such as partnering with the New Frontiers mission OSIRIS-Rex to visit a NEA and return a sample to the Earth. However, a strong consensus of the NEO User Team within xPRP was that a dedicated mission to the asteroid targeted by humans is required [3], ideally including regolith sample return for more extensive characterization and testing on the Earth.

The Case for Mars Sample Return: Returned samples provide a unique perspective on the planetary environment, based on our ability to manipulate the sample, the capability to analyze the sample at high precision and accuracy, and the ability to modify experiments as logic and technology dictates over time [4]. For example, while the results of the Viking life detection experiments are still regarded by some as ambiguous, the return of samples to terrestrial labs would have enabled a battery of tests that would have left no doubt in interpretation of results.

The Decadal Survey sample-return mission will make significant progress regarding questions related to Mars habitability and past potential for life. It requires extensive surface mobility and capability to examine samples *in situ* to ensure the right samples are returned. However, a simpler, "groundbreaking" Mars Sample Return (GMSR) mission has been advanced several times as delivering a significant fraction of important Mars science objectives at a reduced cost. Such a mission architecture would do double duty for science and exploration at a price point well within the Mars Next Decade budget.

Science. The scientific value of a simplified sample return includes characterizing the igneous products and interior evolution of Mars, characterizing surface depositional processes and post-depositional histories, tying absolute ages to relative crater histories, and determining how regolith forms and is modified [5-7]. It is to be emphasized that the science community would not be satisfied with this approach if it were the only sample return mission under consideration for a Mars program; but if it is approached as the first in a series, it would enable paradigm-altering science and satisfy many stated science goals for MSR.

Engineering. Mechanical design and testing relies on knowledge and simulation of the surface environment. Lunar simulant has been extensively used for mobility tests, resource production, human health, and dust control technologies. Particle shape and size, composition, and bulk density may be characterized *in situ*, but more detailed measurements including trace composition, mineralogy relative to size and shape distribution, internal textures and compositions, particle strength, and abrasivity require sample return to create a better testing environment than the current Mars soil simulant JSC Mars-1 [8].

Human health. Recommended measurements needed for human health assessment include the presence of hexavalent chromium, pH and buffer capacity, and abundance of organic carbon [8], which may be done with well-planned in situ investigations. However, parallels with the work done by Lunar Airborne Dust Toxicity Advisory Group [9], which includes not just toxicology but also inhalation, dermal and ocular exposure, suggest that a sample of at least 50 g from the surface is greatly desired (J. James, pers. comm).

Programmatic risk. Currently, planetary protection guidelines dictate that returned Mars samples be kept in a CDC-type containment facility until acceptably tested and sterilized to minimize the threat to life on Earth. On the other hand, the Human Exploration program is considering immersing its crew in the Mars environment for up to 500 days after a slate of *in situ* microbial and toxicity measurements are made. Sample return provides the material to design new tests that cannot yet be imagined but may well become crucial in preventing crew loss at the surface of Mars.

GMSR Mission Architecture: The concept of Groundbreaking Mars Sample Return was developed by MEPAG [10, 11] to lower sample return mission cost and complexity. The GMSR architecture does without precision landing, extensive roving, and *in situ* instrumentation. It consists of a lander, extendable arm, simple sampling devices (scoop, sieve), and a context camera. The mission visits a site previously characterized by other missions to provide context and design envelopes. The collected samples include 500g of soil, dust, rock fragments, and atmosphere.

A direct entry/direct return architecture for MSR has been studied numerous times. A large launch vehicle delivers a payload to the surface of Mars consisting of sample collection and processing capabilities, a sample return capsule, and a Mars Ascent Vehicle (MAV) fueled for an ascent from Mars and flight back to Earth. Upon approach to Earth, the capsule separates from the rest of the vehicle and performs a high-speed re-entry similar to Stardust or Genesis.

Previous studies [12-15] estimate the landed mass of a direct-return mission as 1000-1500 kg (higher estimates include a rover), but find the direct return approach to be prohibitively expensive, because it requires a very large (=costly) large launch vehicle and lander to carry a fully fueled ascent vehicle. However, several advancements in technology encourage a re-examination of the direct return GMSR architecture. We highlight here two relevant developments from MSFC, though others certainly exist.

Launch Vehicle: The Space Launch System (SLS) provides around 50,000 kg to TMI (or 30,000 kg for the initial 70 mT configuation) direct from Earth. In an MSR study enabled by the Constellation-era heavy lift vehicle [16], aerocapture of 40 metric tons (mT) and landing of 8 mT were achieved. In this study, three 500 gm separate samples were returned from two separate Martian locations with a lander and rover having a mobility of >1 km, subsurface sampling, and additional investigations. This capability far exceeds the GMSR mission needs, opening the possibility of a GMSR mission sharing SLS launch capability and perhaps travelling to Mars after being launched to Earth-Moon L2 in an SLS reference mission.

DACS Thrusters: The Robotic Lunar Lander Development Program has invested in high thrust-to-weight thrusters for planetary landers, specifically missile-heritage, miniaturized thruster technologies used for Divert and Attitude Control Systems (DACS). MSFC hot-fire tested 100-lbf and 5-lbf thrusters with MMH/MON-25 under various pulsing durations, power levels, and propellant mixture ratios (Fig. 1). These tests show that DACS thrusters exhibit combustion stability, engine efficiency, and ability to perform pulsed and steady state burns at full power. Such thrusters need to be tested under Mars conditions but hold promise for lowering the mass of the MAV in a GMSR direct return architecture.

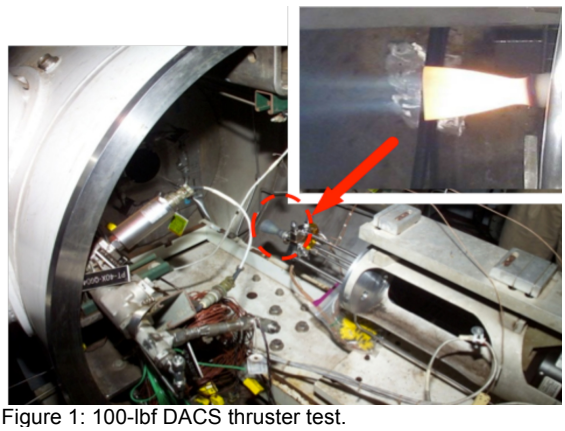
Figure 1: 100-lbf DACS thruster test.

Conclusions: A simplified approach to the first Mars sample return can return samples of paradigm-changing geologic importance and provide detailed knowledge to aid in planning safe and productive human exploration missions. The elements of such a mission (heavy lift, large landers, and high-speed re-entry) can also be used to provide test data for human systems design. Technological advances such as heavy-lift capability in the SLS, trajectories from Earth-Moon L2, and high thrust-to-weight ratio engines may enable a viable single-launch, direct return mission. A Groundbreaking MSR mission has not been updated or costed for a decade, so we suggest that the Mars Program commission an independent engineering and cost estimate for such a mission.

References: [1] Vondrak et al. (2010) Space Sci. Rev. **150**, 7-22. [2] LEAG-SAT (2006) www.lpi.usra.edu/leag/reports/rlep2_4_4_06.pdf. [3] Wargo, M.J. (2012) http://www.lpi.usra.edu/sbag/meetings/jan2012/presentations/0900_Wargo.pdf. [4] Shearer and Borg (2006) Chemie der Erde **66**, 163-185. [5] Treiman et al. (2010) http://www8.nationalacademies.org/ssbsurvey/DetailFileDisplay.aspx?id=77&parm_type=PSDS. [6] MEPAG (2008) Astrobiology **8**, 489-535. [7] iMARS Working Group (2008) http://mepag.jpl.nasa.gov/reports/index.html. [8] National Research Council (2002). [9] Tranfield et al. (2008) Lunar Science Forum 2125. [10] MSR Science Steering Group (2005) http://mepag.jpl.nasa.gov/reports/ndsag.html. [11] MSR Science Steering Group (2002) http://mepag.jpl.nasa.gov/reports/index.html. [12] Gamber and Adams (1992) Mars: Past, Present, and Future 169-181. [13] Price, H., et al. (2000) IEEE Aerospace Conference. [14] Mattingly, Matousek, and Jordan (2002) IEEEAC paper #1392. [15] Wallace, Gamber, Clark (1996) AIAA-96-0336. [16] Langhoff et al. (2008). NASA/CP-2008-214592.

GROUNDBREAKING MARS SAMPLE RETURN FOR SCIENCE AND HUMAN EXPLORATION

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With David Draper, Dean Eppler, Allan Treiman

Recommended reading:
MacPherson et al. (2002) GMSR Study for MSR Science Steering Group
Treiman et al. (2010) Decadal survey white paper (15 coauthors & 72 signatories)

1

LPRP and xPRP: Some Lessons Learned

Concepts and Approaches for Mars Exploration

- Both were precursor robotics programs with input from science, human exploration, and technology
- Missions (LRO, LCROSS) were responsive to science but were not meant to meet Decadal-level goals
- Missions were meant to be part of a series (flybys, orbiters, landers, sample return)
- Sample analysis in terrestrial labs was critical to address Strategic Knowledge Gaps related to geotechnical properties and mobility, mechanical and suit design, and human health assessment

Fun exercise: Revisit the notional xPRP Mars mission plans!
http://www.nasa.gov/pdf/457443main_EEWS_ExplorationsPrecursorRoboticMissions.pdf

2

Groundbreaking Mars Sample Return

Concepts and Approaches for Mars Exploration

- Is responsive to the astrobiological and chronological science goals of MEPAG, Decadal Survey, and E2E-iSAG
- Addresses the chemical & biochemical nature of the surface to fill “Strategic Knowledge Gaps” for human exploration of Mars
- Avoids the MSR appearance of lower priority MAX-C science coupled with initiation of large long term fiscal and political commitment
- Probably fits within cost constraints (cost bogey ~$1B)

3

Groundbreaking Mars Sample Return

Concepts and Approaches for Mars Exploration

- Most of the basic concepts about the Moon (and the basis of our under-standing for all terrestrial planets) arose from compositions present just at Apollo 11 site, a “grab and go”
- For a similar Mars mission, sampling diversity can be achieved via a “locality sample” consisting of lithic fragments, soil, dust, and atmosphere at a single landing site

- Such a sample

  Addresses a large fraction of Mars science objectives for sample return – including astrobiologic investigations

  Provides significant risk mitigation for human exploration

  Naturally enables several important technology advances

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Mars Science Uniquely Addressed by GMSR

Concepts and Approaches for Mars Exploration

- Sample return uniquely benefits goals that rely on trace element analysis, isotopic analysis, independently reproduced results, experimental work, and fine-scale structures or minerals
- **Search for life**
  - Trace organics, biogenic elements & their isotopic compositions, biomarkers
- **Following the water**
  - Alteration rinds, hydrous minerals/veinlets, stable isotope fractionation
- **Surface processes**
  - Extent of regolith gardening, nature and thickness of coatings, exposure ages
- **Basic planetology**
  - Ages and compositions of materials set in geologic context, isotopic tracers of source regions and reservoirs
- **Ground truth / experience** for complementary missions
  - Enormous context for orbital missions
  - Feed-forward to later, more highly targeted MSR missions

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Mars SKGs Uniquely Addressed by GMSR

Concepts and Approaches for Mars Exploration

GROUP B. Humans to the Martian Surface	Orbital	Lander / In Situ	Sample Return
1. Back Contamination to Earth. We do not know whether the Martian environments to be contacted by humans are free, to within acceptable risk standards, of biohazards that might have adverse effects on some aspect of the Earth's biosphere if uncontained Martian material were returned to Earth.	None	Limited	Full
4. Dust Effects. We do not understand the possible adverse effects of Martian dust on either the crew or the mechanical/ electrical systems.	Very limited	Limited	Full
5. Atmospheric ISRU. We do not understand in sufficient detail the properties of atmospheric constituents near the surface to determine the adverse effects on ISRU atmospheric processing system life and performance within acceptable risk for human missions.	Limited	Most	Full
6. Forward Contamination to Mars. We are not able to predict with sufficient confidence the potential consequences of the delivery and subsequent dispersal of a large bioload associated with a future human mission to the martian surface.	Limited	Limited	Full
8. Landing Site and Hazards. We do not yet know of a site on Mars that is certified to be safe for human landing, and for which we understand the type and location of hazards that could affect the ability to safely carry out mobile surface operations.	Limited	Most	Full
9. Technology: Mars Surface. (3) enable human mobility and exploration of the Mars surface environment within acceptable risk.	Very limited	Limited	Full

GMSR Architecture

Concepts and Approaches for Mars Exploration

- Many GMSR studies and architectures exist already (see references in our abstract and others in this session)
- GMSR architecture consists of a lander, extendable arm, simple sampling devices (scoop, sieve), and a context camera
- GMSR does without precision landing, extensive roving, and in situ instrumentation
- GMSR visits a site previously characterized by other missions to provide geologic context and design envelopes
- GMSR naturally incorporates technology desires in EDL, Mars ascent, and sample handling

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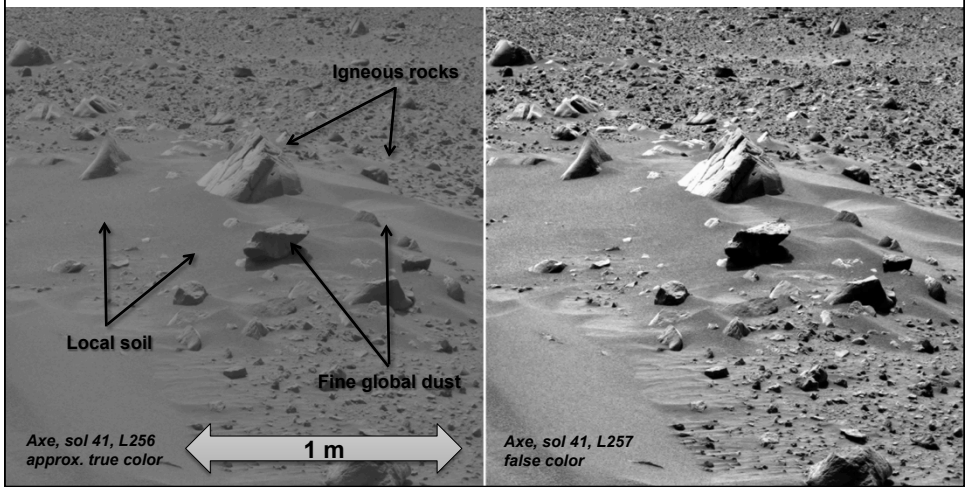
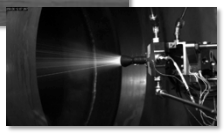
Proof-of-Concept: Gusev Plains (iSAG ref site)

Concepts and Approaches for Mars Exploration

- Impacts strew basaltic rocks from Hesperian lava flow from at least 10 m depth
- Drifts of soil with particle sizes <2 mm formed from local rocks
- Rocks and dunes coated in bright dust with constant (global) composition



New Technologies Enabling GMSR



Concepts and Approaches for Mars Exploration

- Space Launch System (SLS)
  - Provides ~50 MT to TMI direct from Earth
  - This capability far exceeds the GMSR mission needs; possibility of sharing SLS launch capability and perhaps travelling to Mars after being launched to Earth-Moon L2 in an SLS reference mission
  - Alternatively, can use extra delivery mass to enable fully-powered descent
- Sky Crane
  - Enables 900 kg landed mass
- Miniaturized ascent thrusters
  - Missile-heritage thruster technologies Divert and Attitude Control Systems (DACS) tested at MSFC for lunar case, show promise for MAV (and maybe descent) stages (others later this session)
- SEP and/or solar sails
  - Enables lower-mass return-to-Earth stages (see N. Strange, L. Johnson abstracts)

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GMSR: Worth Another Look

Concepts and Approaches for Mars Exploration

- GMSR achieves a significant overlap between fundamental Mars science, human exploration, and technology desires
  - Programmatic risks are bought down across all directorates
  - Meets political cadence and avoids multimission commitment
- New technology development (launch vehicles, landing technology, etc.) enables GMSR
- GMSR hasn't been seriously studied or costed for more than a decade

We recommend that the Mars Program commission a study of groundbreaking MSR as a mid-term mission, aiming for $1-1.2B class mission

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MEPAG Goal	Objective	Investigation
GOAL I.: DETERMINE IF LIFE EVER AROSE ON MARS	Objective A: Characterize past habitability and search for evidence of ancient life	Determine the major processes that degrade or preserve complex organic compounds, focusing particularly on characterizing oxidative effects in surface and near-surface environments (including determination of the "burial depth" in regolith or rocks that may shield from such effects), the prevalence, extent, and type of metamorphism, and potential mechanisms and rates for obscuring isotopic or stereochemical information.
		Characterize organic chemistry, including (where possible) stable isotopic composition and stereochemical information. Characterize co-occurring concentrations of possible bioessential elements; stable isotopic composition of prospective metabolites
	Objective B: Characterize present habitability and search for evidence of extant life	Evaluate the physicochemical conditions of actual surface regolith or rock environments in terms of the potential for degrading or preserving biosignatures, and the effects of these processes on specific types of potential biosignatures.
		Seek evidence of ongoing metabolism, in the form of rapid catalysis of for extant life, stable isotopic fractionation, and/or strong chemical gradients.
	Objective C: Determine how the long-term evolution of Mars affected the physical and chemical environment critical to habitability and the possible emergence of life	Constrain evolution in the geological, geochemical, and photochemical processes that control atmospheric, surface, and shallow crustal chemistry, particularly as it bears on provision of chemical energy, and availability (abundance, mobilization, and recycling) of bioessential elements.
		Constrain the nature and abundance of possible energy sources as a function of changing water availability, geophysical and geochemical evolution, and evolving atmospheric and surface conditions.
GOAL II: CLIATE ON MARS	Objective A.: Characterize Mars' Atmosphere, Present Climate, and Climate Processes Under Current Orbital Configuration	
	Objective B.: Characterize Mars' Recent Climate and Climate Processes Under Different Orbital Configurations	Determine the chronology, including absolute ages, of compositional variability, and determine the record of recent climatic change that are expressed in stratigraphy
	Objective C.: Characterize Mars' Ancient Climate and Climate Processes	Find physical and chemical records of past climates.
GOAL III: DETERMINE THE EVOLUTION OF THE SURFACE AND INTERIOR OF MARS	Objective A.: Determine the nature and evolution of the geologic processes that have created and modified the Martian crust	Determine the formation and modification processes of the major geologic units and surface regolith as reflected in their primary and alteration mineralogies.
		Understand sedimentary processes via ages, sequences, and mineralogies of sedimentary rocks; rates, durations, environmental conditions, and mechanics of weathering, cementation, and transport.
		Constrain the absolute ages of major Martian crustal geologic processes, including sedimentation, diagenesis, volcanism/plutonism, regolith formation, hydrothermal alteration, weathering, and the cratering rate.
		Evaluate igneous processes and their evolution through time. Understanding primary lithologies also is a key to interpreting alteration processes that have produced secondary mineralogies.
		Characterize surface-atmosphere interactions on Mars, integrating information about the morphology, chemistry and mineralogy of surface deposits.
		Determine the nature of crustal magnetization and its origin.
	Objective B.: Characterize the structure, composition, dynamics, and evolution of Mars' interior	Determine the chemical and thermal evolution of the planet, using mineralogy, geochemistry, and isotopic analysis of xenoliths in volcanic and plutonic rocks.
	Objective C.: Understand the origin, evolution, composition and structure of Phobos and Deimos	

PREDECISIONAL FOR PLANNING AND
DISCUSSION PURPOSES ONLY